Radio Frequency Subsystem (RFS)

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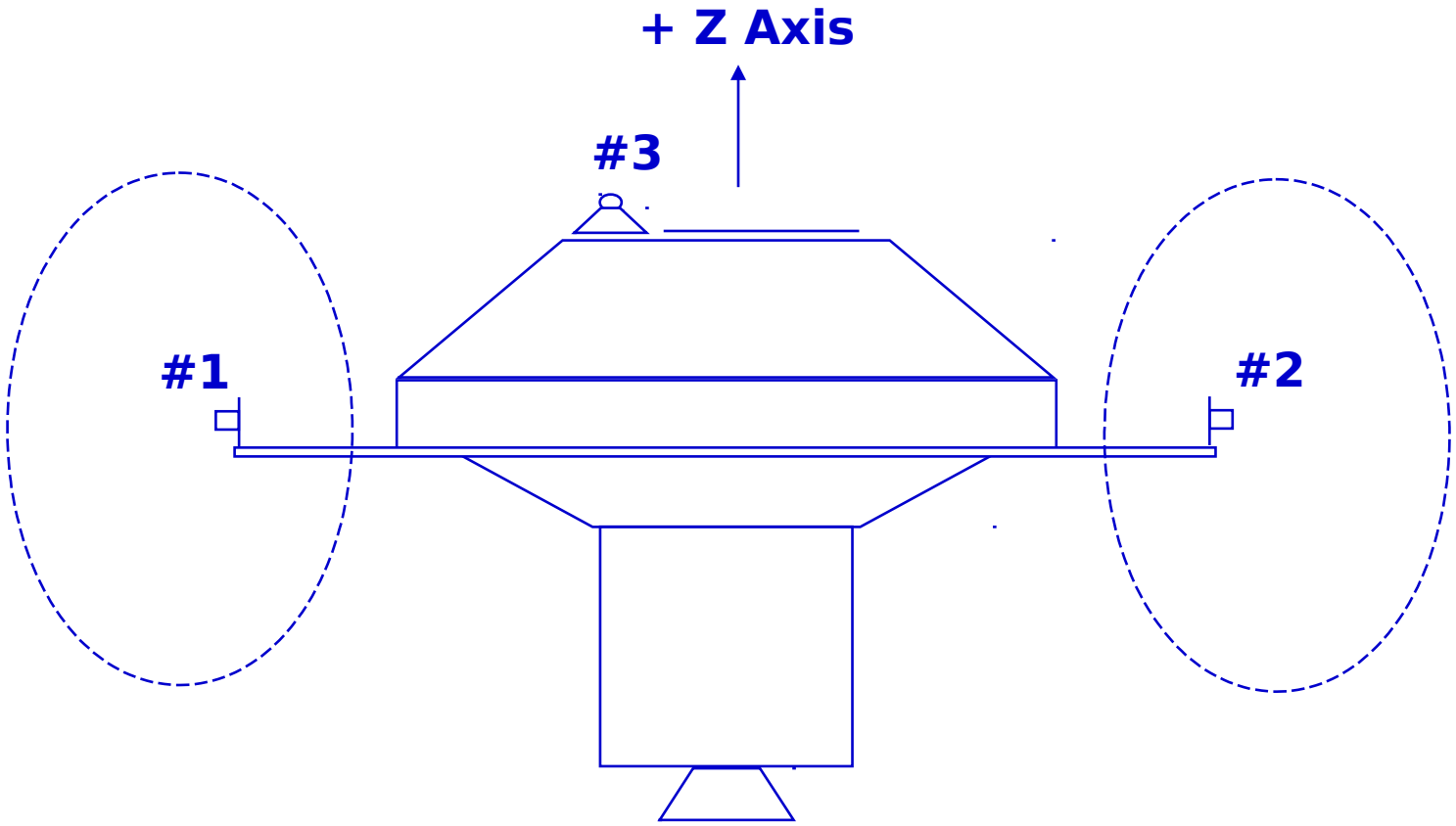
Top Level Requirements

- **Provide Spacecraft 2 Kbps Command Capability at Any Vehicle Orientation**
- **Provide Subcarrier Mode Low Rate 1 Kbps Minimum Telemetry for Emergency, Safe-hold, and Initial Acquisition Operations at Any Vehicle Orientation**
- **Provide Wideband Downlink at 500 Kbps for Normal Mission Operations**
- **Provide Wideband Downlink From 250 Kbps to 500 Kbps for Limited Link Margin Operations**
- **Provide Coherent Range and Range Rate Capability 3m, 3mm/s (3sigma)**
- **Compatible With NASA 34m BWG and NRL BP Ground Stations**
- **Frequency Allocation & Spectrum Requirements**
  - **DSN Category A Space Research Service (U/L 2025 – 2110mhz, D/L 2200 – 2290mhz)**
  - **CCSDS Compatible**
  - **Comply With NTIA Frequency Management Regulations**

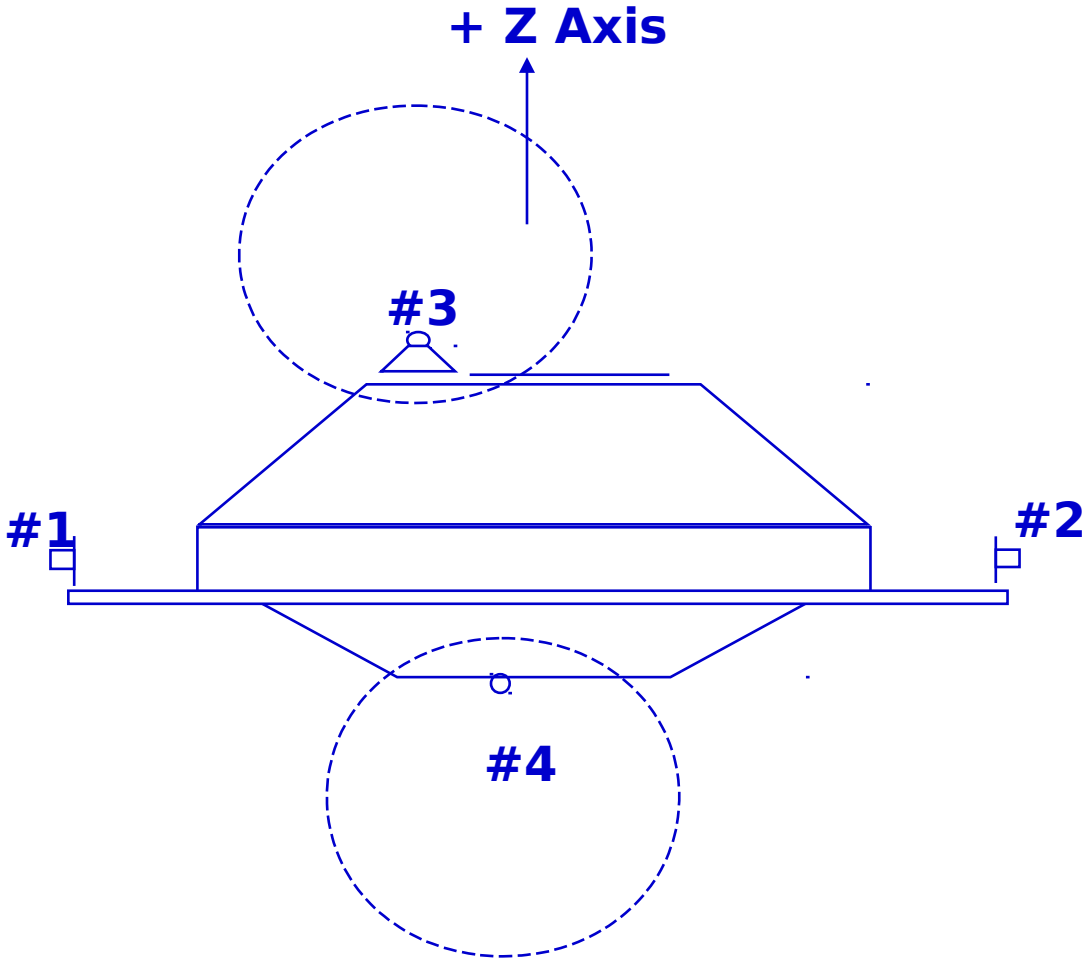
Current Baseline/Approach

Launch / Insertion Configuration



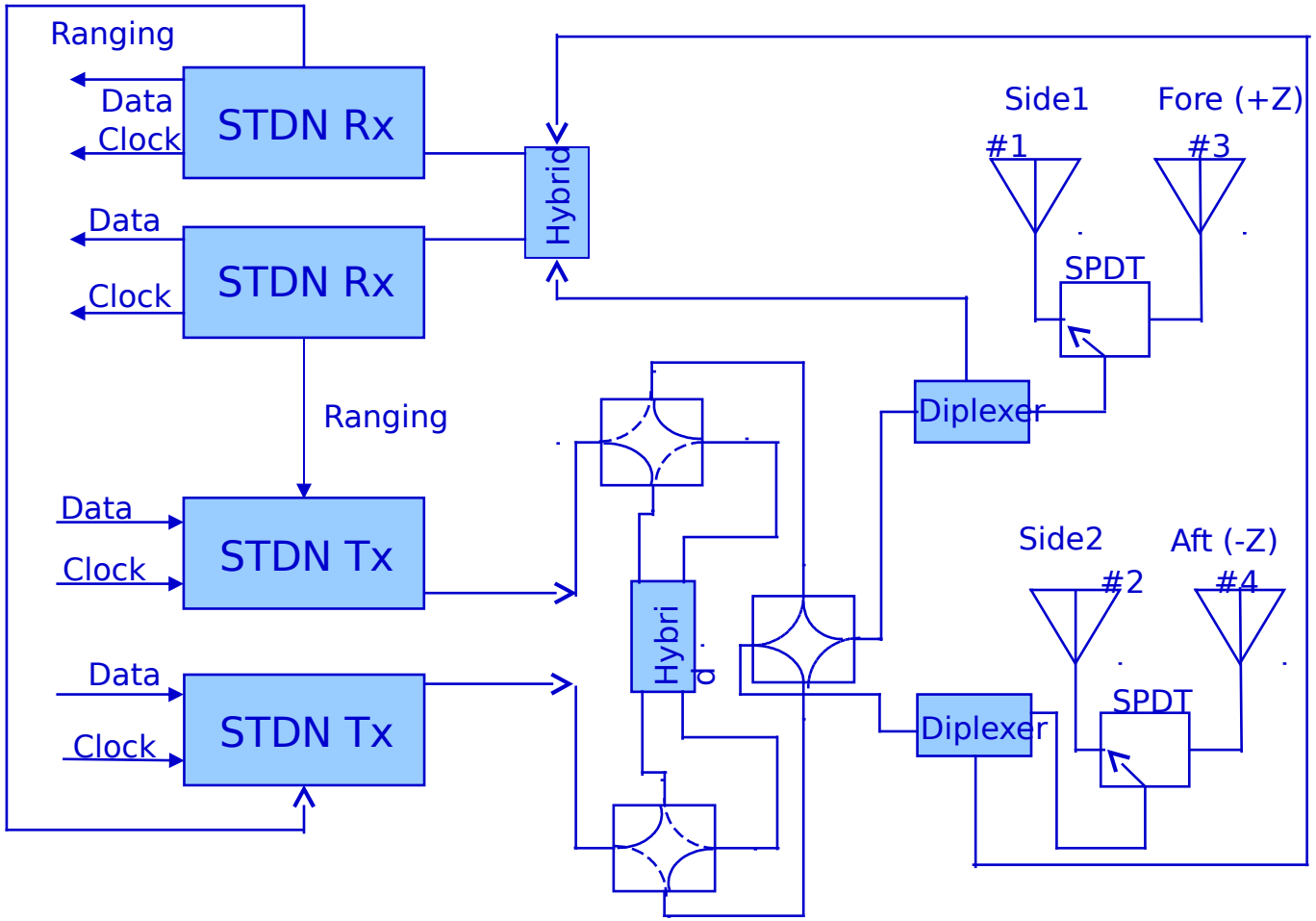
Omni Configuration Uses BOTH Mini Helix Antennas

Operational Configuration



Hemispherical Configuration Uses EITHER +Z OR -Z Waveguide Antennas

RF Subsystem Block Diagram



Uplink

- S-Band Uplink, 2093.882917mhz
- BP for GEO Mission Ops, DSN For Launch, Insertion and Back-up
- Command Data = 2kbps, NRZ-M Data BPSK Modulated Synchronously on a 16khz Sinewave Subcarrier
- Uplink Subcarrier Modulation Index = 1 Radian Peak
- Link Margin Worst Case = 10.6 Db for BER 1 X 10^-6
  - BP (13m, 5 Deg El) Uplink Into Spacecraft Omni Pattern Null At GEO
- Output to CTDH
  - RS-422 NRZ-L Data & Clock
  - TTL Subcarrier Lock Indicator
  - TTL Carrier Lock Indicator

Downlink

- S-Band Downlink 2273.9 MHz (STDN Tx / Rx Ratio = 240/221)
- BP For GEO Mission Ops., DSN 34m BWG for Launch, Insertion, & Back-up
- Subcarrier Data Mode for Insertion, Simultaneous Telemetry + Ranging, and Safe-Hold Mode
  - 1 Kbps (2 Ksps) NRZ-M, BPSK Modulated Onto 1.7 MHz Subcarrier Phase Modulated Onto S-band Carrier at Mod Index of 1.6 Radians Peak
- Wideband Data Mode for Normal Mission Operations 500 Kbps (1ksps) NRZ-M, BPSK Modulated Onto S-Band Carrier Capable of Data Rates Down to 250 Kbps for Limited Link Margin Operations
- Input From CT&DH Is RS-422 Data and 2 X Clock for Both Wideband & S.C. Mode

Summary of Downlink Analyses

Subcarrier Mode 1kbps

- **Link Margin Worst Case Over All Conditions = 13.6dB (BER 1x10^-7)**
  - **D/L From Spacecraft Omni Null**
    - **BP(13m) at 5 deg Elevation Maximum Pointing, Polarization, & Atmospheric Losses**
  - **Transmitter @ Worst Case RF Power Out**
  - **Maximum Spacecraft Losses for Diplexer, Cable, Switches**

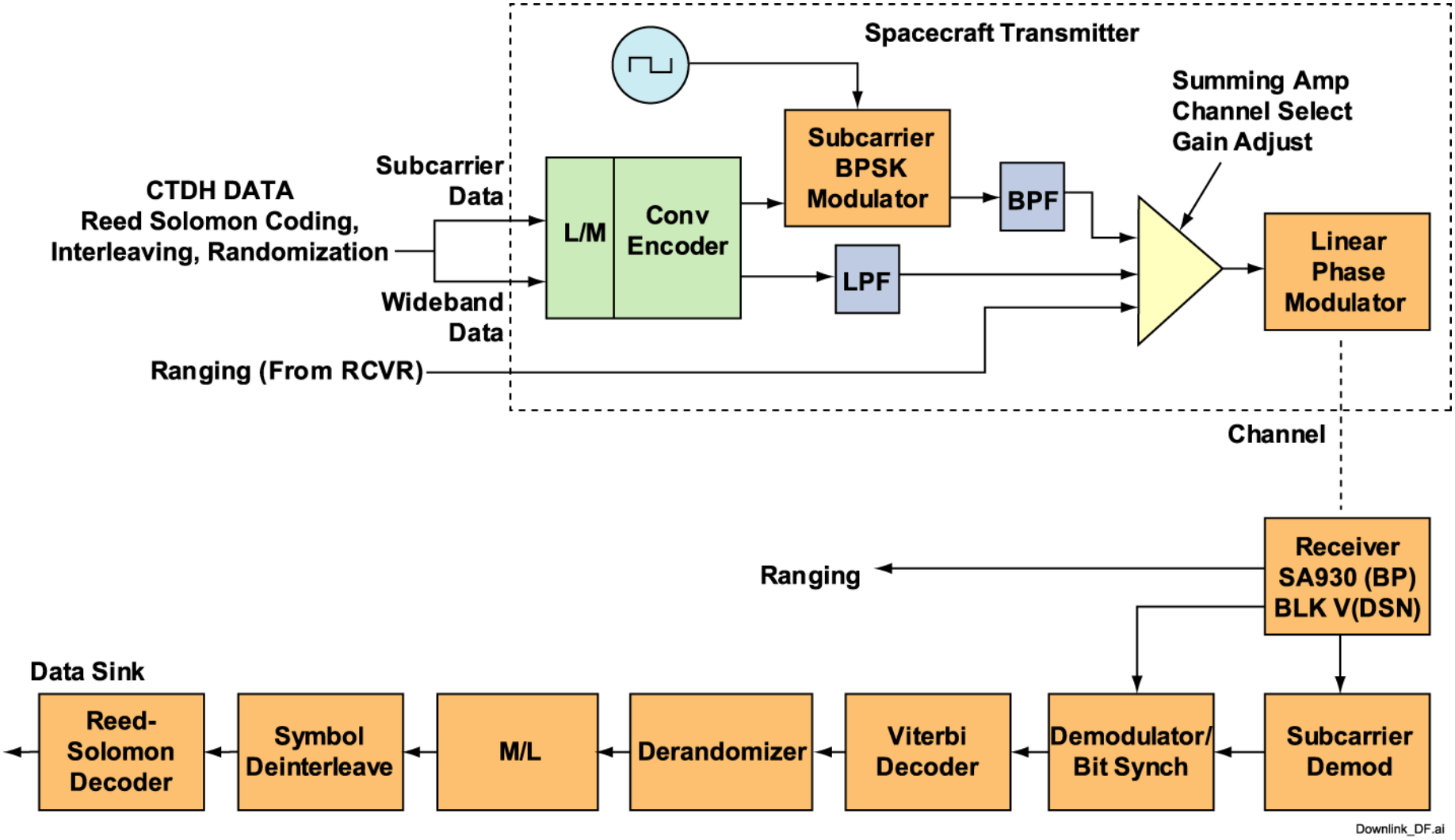
Wideband Mode 500kbps

- **Link Margin Worst Case >3.0 dB Over 94% of Sphere (BER 1x10^-7)**
  - **D/L to BP(13m) at 5 deg Elevation**
  - **Maximum Pointing, Polarization, & Atmospheric Losses**
  - **Transmitter @ Worst Case RF Power Out**
  - **Maximum Spacecraft Losses for Diplexer, Cable, Switches**

Wideband Mode 250kbps,

- **Link Margin Worst Case > 2.5 dB Over 100% of Sphere (BER 1x10^-7)**
  - **D/L to BP(13m) at 5 deg Elevation**
  - **Maximum Pointing, Polarization, & Atmospheric Losses**
  - **Transmitter @ Worst Case RF Power Out**
  - **Maximum Spacecraft Losses for Diplexer, Cable, Switches**

Downlink Data Flow



Ranging

- **Ranging Signal Phase Modulated Directly Onto Uplink Carrier At Mod Index of .5 Radian**
- **Sequential Square Wave Ranging (1.01 kHz to 515 kHz)**
- **Ranging Signal Demodulated From Uplink and Phase Modulated Directly Onto Downlink Carrier At Mod Index of .5 Radian**
- **Downlink Carrier Reference Generated From Uplink Carrier for Coherent Operation**
- **Non-Coherent Downlink Operation Using On-Board Reference Oscillator When Uplink Is Not Present and Ranging Not Required**

Summary of Ranging Link Analysis

- **Link Margin Worst Case Orbit Insertion = 10.9 Db (Pr/no >30db)**
  - **U/L & D/L Via Spacecraft Side Omni Antennas Worst-Case Null**
  - **U/L & D/L Via BP*(13m) at 5 Deg Elevation**
  - **Maximum Pointing, Polarization, & Atmospheric Losses**
  - **Transponder @ Worst Case Sensitivity & RF Power Out**
  - **Maximum Spacecraft Losses for Diplexer, Cables, Switches, Hybrid**

- **Link Margin Worst Case "On Station" = 11.7 Db (Pr/no >30db)**
  - **U/L & D/L From Spacecraft Waveguide Antenna 90 Deg off Boresite**
  - **U/L & D/L Via BP (13m) at 5 Deg Elevation**
  - **Maximum Pointing, Polarization, & Atmospheric Losses**
  - **Transponder @ Worst Case Sensitivity & RF Power Out**
  - **Maximum Spacecraft Losses for Diplexer, Cables, Switches,hybrid**

*** DSN Will Be Used for Launch & Insertion Phases, Link Margin for DSN = 17.4 dB**

Issues

- **There Are a Few Times During the Mission Which Require Line Of Sight Angles to the Spacecraft Z Axis of Close to 90 Degrees for Periods of 1-4 Days**
  - **This Could Require Extended Periods of D/L Rate of 250kbps**
- **Data Processing and Mission Operations Have Allowed for Such Low Data Rate Periods In Overall Mission Planning and Error Budgeting**

Status

NTIA Stage II Frequency Allocation Approved

- **Transponder:**
  - **Specification In Revision, Released and Reviewed by Vendor Prior to De-Scope**
  - **Vendor Has Flight Qualified Similar (SGLS) Transponders for Coriolis and SBRIS**
  - **EM STDN Transponder Built and Tested**
- **Diplexers:**
  - **Successfully Re-Tuned ICM Diplexers to FAME Frequency**
    - **Quote Received From ICM Vendor for FAME Diplexers**
- **Mini Helix Antennas:**
  - **Flight Qualified for XS-S10 (Clementine II) Qual Models From XS-S10 In-House**
- **Waveguide Antennas:**
  - **EM Models Built and Tested**
  - **-Z Tested On Current Spacecraft Configuration**
  - **+Z Tested On Original Spacecraft Configuration**
  - **+Z Mock-Up of Current Configuration In Progress**

Components

Component	Manufacturer Time	Lead	Level	Heritage
Transponders	L-3 Months	15	Proto-flight (Mil Hdbk 340a)	Similarity to Flight-Qualified SGLS Units
Switches	Dow-Key Months	8	Flight	Clementine, ICM Many Others
Diplexers	Narda West Months	8	Flight	ICM
Helix Antennas (Side)	NRL Months	4	Flight	XS-S10
Waveguide Antennas (Top & Bottom)	NRL Months	10	Flight	To Be Fully Qualified In-house
Hybrid Splitter / Combiner	Macom Months	6	Flight	XS-S10, ICM Clementine

Schedule Milestones

• Release Transponder Specification Rev A	11/30/01
• Award Transponder Contract	01/25/01
• Award Diplexer & Switch Contracts	05/31/02
• Delivery of Diplexers & Switches	Feb. 03
• RF EAGE Complete	02/03/03
• Delivery of Transponder 1	02/30/03
• Delivery of Transponder 2	03/30/03
• DSN / BP Transponder Compatibility Tests	Mar. Apr. 03
• Delivery of Antennas	3/30/03
• RF Subsystem Verification Complete	5/18/03
• RF Subsystem Deck Integration	6/20/03

Backup

Uplink Budget (Omni, Geo)

	Blossom Pt.	DSN 34m BWG
Transmitter Power BP=500W, DSN=1000W	57 dBm	60 dBm
Line & Diplexer Losses	-1.0 dB	-0.2 dB
Antenna Gain BP = 13M DSN = 34M BWG	46.5 dBi	56 dBi
Free Space Loss (Geosync at 5 Degrees Elevation)	-191.2 dB	-191.2 dB
Polarization & Pointing Loss	-0.4 dB	-0.4 dB
Atmosphere Loss	-0.4 dB	-0.4 dB
Min. SC Antenna Gain (Side Antennas W/ 3db Hybrid) *	-15 dBi	-15 dBi
Spacecraft Losses (Dplxr, SPDT, 12 Ft Gore G4 Cable)	-2.9 dB	-2.9 dB
Received Signal At Receiver	-107.4 dBm	-94.1 dBm
Receiver Sensitivity for BER 1x10^-6	-118 dBm	-118 dBm
Margin	10.6 dB	23.8 dB

- During Normal GEO Mission Operations, +Z or –Z Antenna Is Used

Min SC Antenna Gain = -5db. Margin @ BP = 20.6db

Downlink Budget (1 kbps, Geo)

	Blossom Pt.	DSN 34m BWG
Transmitter Power (5W)	37.0 dBm	37.0 dBm
Modulation Loss (Worst Case W/ Ranging)	-2.4 dB	-2.4 dB
Spacecraft Losses (Cables, Diplexer, Switches)	-3.1 dB	-3.1 dB
Min. Spacecraft Ant Gain (Includes 3db Hybrid)	-15.0 dBi	-15 dBi
Free Space Loss (5 Degrees Elevation)	-191.9 dB	-191.9 dB
Atmosphere Loss (5 Degrees Elevation)	-0.4 dB	-0.4 dB
Pointing & Polarization Loss	-0.4 dB	-0.4 dB
Data Rate (10 Log 1000)	-30.0 dBHz	-30.0 dBHz
Receive G/T (13m Dish at BP, 34m Dish at DSN)	26.0 dB/K	39.0 dB/K
Boltzman's Constant	198.6 dBm/Hz/K	198.6 dBm/Hz/K
Eb/No	18.4 dB	31.4 dB
Implementation Loss	-2.0 dB	-1.0 dB
Required Eb/No (1x10^-7 Per CCSDS 101.0b-3)	-2.8 dB	-2.8 dB
Margin	13.6 dB	27.6 dB

Downlink Budget (500kbps, Geo)

	Blossom Pt.
Transmitter Power (5W)	37.0 dBm
Diplixer & Switch Losses	-0.6 dB
Line Loss (12 Ft. Gore G4 Type Cable W/ Connectors)	-2.2 dB
Minimum Antenna Gain (85 Degrees off Boresite)	-1 dBi
Free Space Loss (5 Degrees Elevation)	-191.9 dB
Atmosphere Loss (5 Degrees Elevation)	-0.4 dB
Pointing & Polarization Loss	-0.4 dB
Data Rate (10 Log 500000)	-57.0 dBHz
Receive G/T (BP 13m Dish at 5 Degrees Elevation)	26.0 dBK
Boltzman's Constant	198.6 dBm/Hz/K
Eb/No	8.1 dB
Required Eb/no (1x10^-7ber Per CCSDS 101.0b-3)	2.8 dB
Implantation Loss	2.0 dB
Margin	3.3 dB

Downlink Budget (250 kbps GEO)

	Blossom Pt.
Transmitter Power (5W)	37.0 dBm
Diplexer & Switch Loss	-0.6 dB
Line Loss (12 Ft. Gore G-4 Cable W/ Connectors)	-2.2 dB
Worst Case Antenna Gain (90 Degrees off Boresite)	-4.8 dBi
Free Space Loss (5 Degrees Elevation)	-191.9 dB
Atmosphere Loss (5 Degrees Elevation)	-0.4 dB
Pointing & Polarization Loss (< .1 Deg Accuracy)	-0.4 dB
Data Rate (10 Log 250000)	-54.0 dBHz
Receive G/T (13m Dish at BP, 5 Deg. Elevation)	26.0 dB/K
Boltzman's Constant	198.6 dB/Hz/K
Eb/No	7.3 dB
Implementation Loss	2.0 dB
Required Eb/No (1x10^-7 BER Per CCSDS 101.0b-3)	2.8 dB
Margin	2.5 dB

Ranging Link Budget

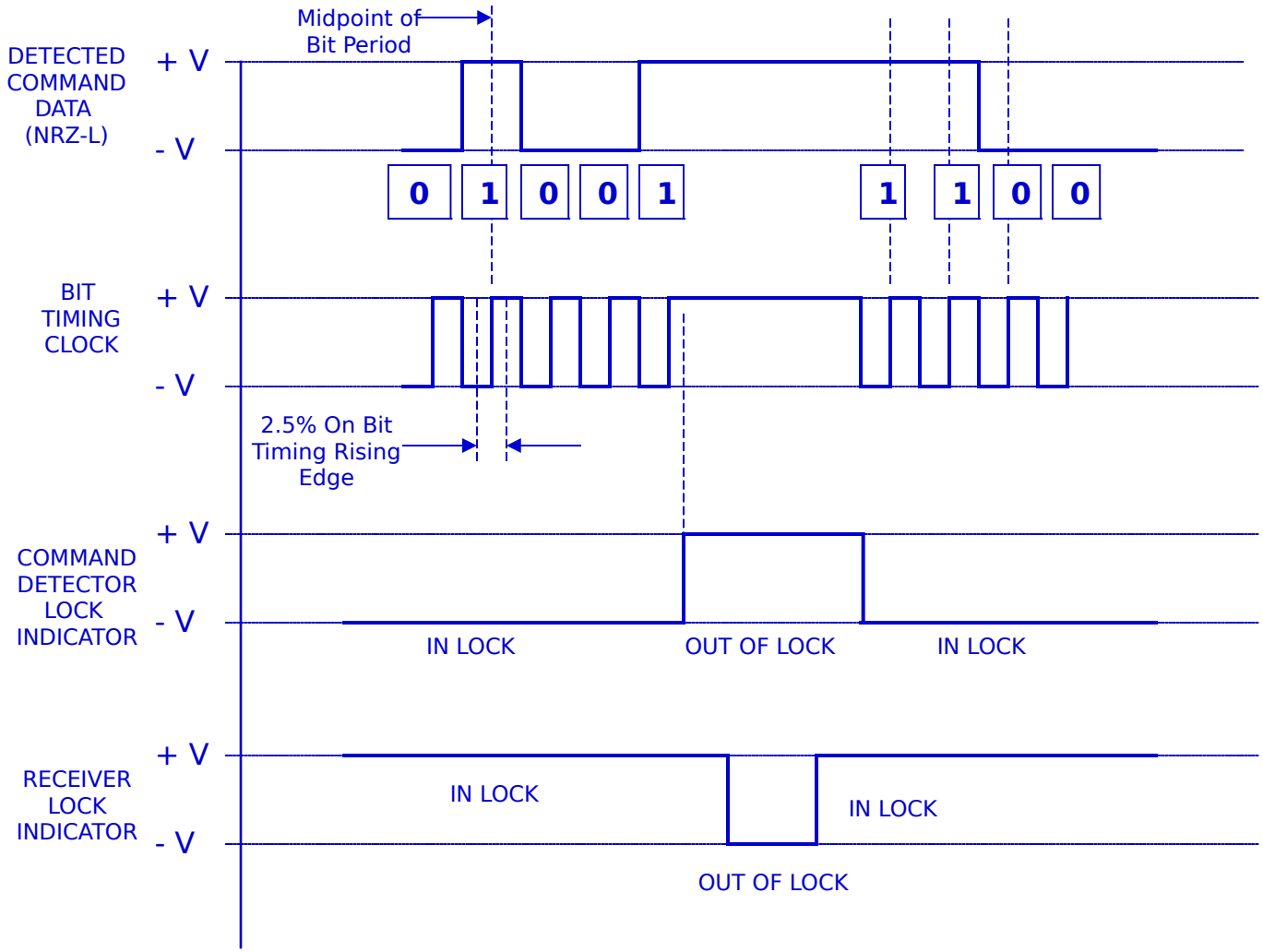
	Blossom Pt.	DSN 34m
U/L Transmit Power (BP 500W / DSN 34m BWG 1KW)	57.0 dBm	60.0 dBm
U/L Modulation Loss	-7.3 dB	-7.3 dB
U/L Line Loss	-1.0 dB	-0.2 dB
U/L Transmitter Antenna Gain (13m BP / 34m DSN)	46.5 dBi	56.0 dBi
U/L Path Loss	-191.2 dB	-191.2 dB
Pointing, Polarization & Atmosphere Loss (5 degrees elevation)	-0.8 dB	-0.8 dB
U/L Minimum Receive Ant Gain (side omnis)	-15 dBi *	-15 dBi
U/L Receive Line Loss (cables, switches, diplexer)	-2.9 dB	-2.9 dB
U/L Received Power	-114.7 dB	-101.4 dB
U/L Receiver Noise Density	-169.7 dBm/Hz	-169.7 dBm/Hz
U/L Pr/No	55.0 dB	68.3 dB
D/L Minimum Transmit Power (5W)	37 dBm	37 dBm
D/L Modulation Loss	-9.3 dB	-9.3 dB
D/L Line Loss (cables, switches, diplexer)	-2.8 dB	-3.1 dB
D/L Transmit Antenna Gain (+/- Z antennas / side omnis)	-8.0 dBi *	-15 dBi
D/L Path Loss	-191.9 dB	-191.9 dB
Pointing, Polarization, & Atmosphere Loss (5 degrees elevation)	-0.8 dB	-0.8 dB
D/L Receive Antenna Gain (BP 13m / DSN 34m BWG)	47.2 dBi	55.7 dBi
D/L Received Power	-128.6 dB	-127.4
D/L Noise Density	-177.4 dBm/Hz	-182.0 dBm/Hz
D/L Pr/No	48.8 dB	54.6 dB
(U/L Pr/No)/(D/L Pr/No)	47.9 dB	54.4 dB
-10 Log (Measurement Bandwidth (5Hz))	-7.0 dBHz	-7.0 dBHz
Pr/No	40.9 dB	47.4 dB

* Once “On Station” The +/- Z Antennas are used = -4.8 dB 90 deg off boresite and Margin =11.7

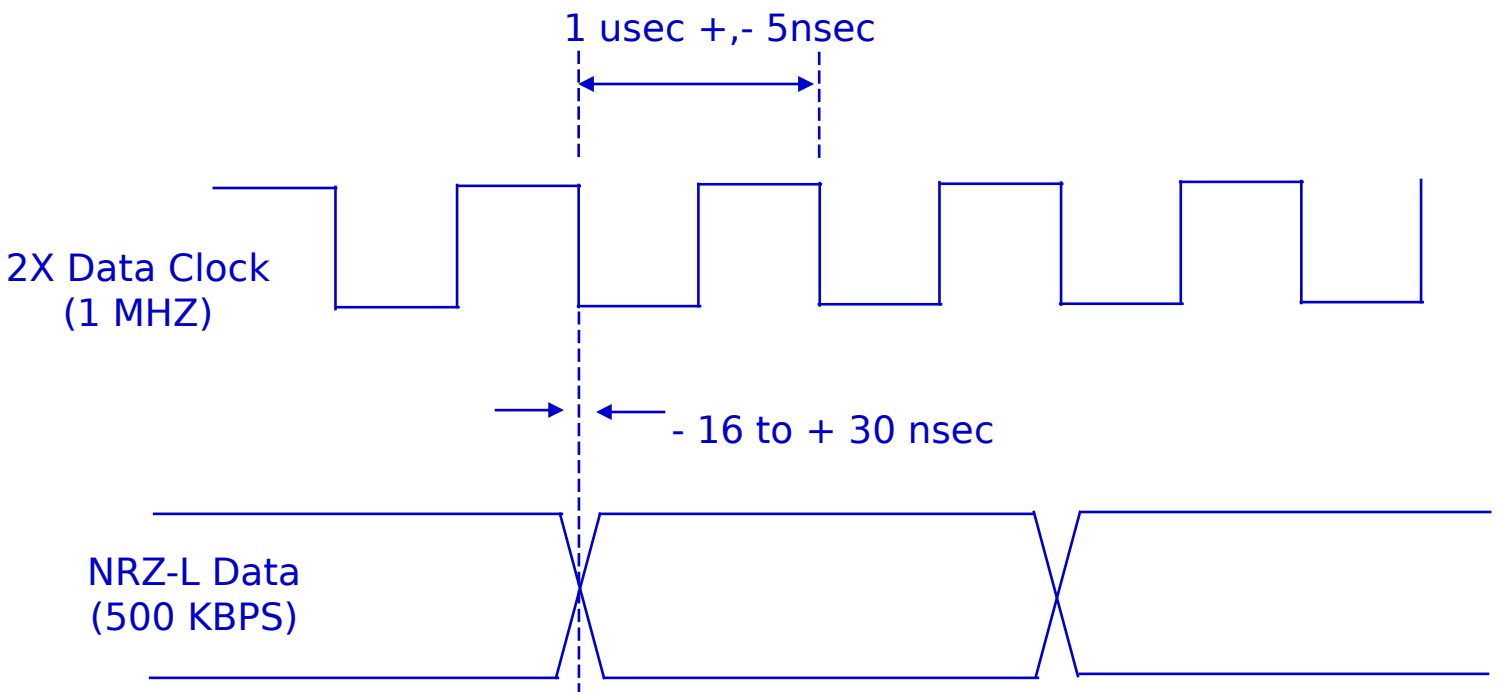
RF Subsystem Electrical I/O

- Transponder Commands: 26V Pulses to Latching Relays
- Transponder Telemetry: Discrete 5V, 0 – 5V Analog, and Passive
- Uplink Command Output
  - Clock & Data RS-422, NRZ-L
  - Receiver Lock and Subcarrier Lock, TTL
- Downlink Data Input
  - 2x Clock and Data RS-422, NRZ-L
- Transfer Switches and SPDT RF Switches: 26V Pulses to Latching Relays
- DC Power,
  - XMTR, 38W @ 22 - 36V
  - RCVR, 4W @ 22-36V

Receiver to CT&DH I/O



CT&DH to Transmitter I/O



500 KBPS Data Rate Shown. Timing Is Scalable To 1 Kbps

Transponders

- **Manufacturer:** L-3 Conic
- **Part #** CXS-610 STDN Transponder
- **Heritage:** SGLS Version (CXS 810) Has Been Qualified for CORIOLIS, SBRIS
  - STDN Transmitter Identical to SGLS Accept Different Freq. Ratio
  - STDN Receiver Similar to Qualified SGLS Unit
  - EM Model of STDN Unit Built and Functional Testing Complete
  - Previous L-3 Conic CXS-800B Used for Clementine
- **Dimensions:** 5.50” W x 7.77” D x 2.025” H
- **Mass:** 5.0 lbs. Max

conic xponder.tif

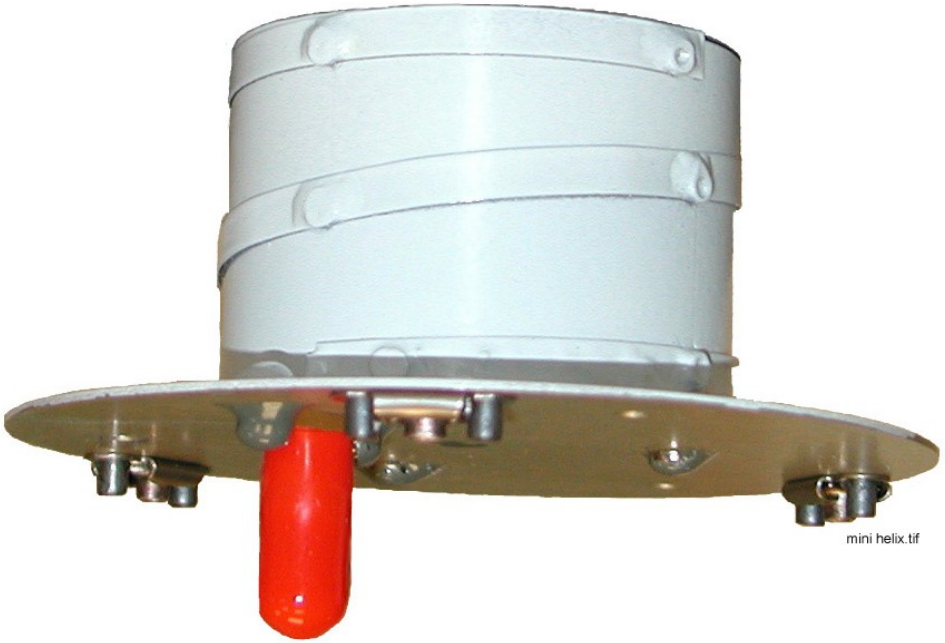
Diplexers

- **Manufacturer:** **Narda West**
- **Heritage:** **Qualified for ICM**
- **Dimensions:** **2.67” W x 6.0” D x 2.4” H**
- **Mass:** **1.4 lbs**

Transmit Channel (ICM Data)				Receive Channel (ICM Data)			
Parameter	Freq (MHz)	-20 C	+60 C	Parameter	Freq (MHz)	-20C	+60C
Rtn Loss	Ft $\pm$ 10	23.4 dB	23.9 dB	Rtn Loss	Fr $\pm$ 5	25 dB	25 dB
Ins Loss	Ft $\pm$ 10	.20 dB	.24 dB	Ins Loss	Fr $\pm$ 5	.39 dB	.47 dB
Ripple	Ft $\pm$ 10	.03 dB	.03 dB	Ripple	Fr $\pm$ 5	.01 dB	.02 dB
Delta Delay	Ft $\pm$ 10	0.5 ns	0.9 ns	Delta Delay	Fr $\pm$ 5	0.4 ns	0.82 ns
Rejection	Fr $\pm$ 5 2 Ft 3Ft 4Ft	49.6 dB 63.7 dB 85.0 dB 53.1 dB	48.7 dB 63.0 dB 85.0 dB 53.4 dB	Rejection	Ft $\pm$ 10 2217 – 6G 6G – 13.5G 13.5G – 16G	70.6 dB 56.2 dB 48.6 dB 48.8 dB	71.4 dB 57.7 dB 51.4 dB 50.5 dB
Isolation	Fr $\pm$ 5	49.8 dB	49.5 dB	Isolation	Ft $\pm$ 10	70.7 dB	71.4 dB

Side Antennas

- **Type:** Miniature Helix
- **Pattern:** Hemisphere, 2 Antennas Arrayed Through 90 Degree Hybrid to Create Spherical Omni Pattern
- **Source:** NRL
- **Heritage:** Qualified for Air Force XS-S10 Micro Satellite
- **Mass:** 0.1 lb


mini helix.tif

+Z and –Z Antennas

- **Type:** **Waveguide Fed Radiator With Conical Reflector**
- **Pattern:** **Hemisphere**
- **Source:** **NRL**
- **Heritage:** **TBD**
- **Mass** **1.5 lb**

- **Type:** **Waveguide Fed Radiator**
- **Pattern:** **Hemisphere**
- **Source:** **NRL**
- **Heritage:** **TBD**
- **Mass:** **.8 lb**

Switches

- Type: RF Coaxial Transfer Switch, Latching, 28V Pulse, w RPI
- Manufacturer: Dow Key Microwave
- Heritage: Clementine, ICM, Others
- Mass: .225 lbs
- Insertion Loss: < .15 dB per Contact 2-3 GHz
- MTBF: > 1 Million Cycles

- Type: RF Coaxial SPDT Switch, Latching, 28V Pulse, w/ RPI
- Manufacturer: Dow Key Microwave
- Heritage: Clementine, ICM, Others
- Mass: .125 lbs
- Insertion Loss: < .15 dB, 2-3 GHz
- MTBF: > 1 Million Cycles